RESEARCH DEPARTMENT

VERTICALLY POLARISED BAND III AERIAL FOR CRYSTAL PALACE

Report No. E-052

(1955/33)

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SUMMARY

This report describes the first stage in the development, using a small-scale model, of a vertically-polarised aerial for radiating two television programmes in Band III from the Crystal Palace television station. The aerial consists of 8 tiers of tangential batwing elements mounted on a 4 ft 4 in. (1·32 m) square section of the tower.

1. INTRODUCTION.

One or two vertically-polarised aerials may be required for radiating Band III transmissions from the Crystal Palace television station. The object of the investigation described in this report was to implement an early proposal to radiate two programmes, together with their associated sound signals, from a single 8-tier aerial. The vision carrier frequencies were to be spaced 10, 15 or 20 Mc/s apart, the most probable allocations of channels being Nos. 6 and 9 (vision carrier frequencies 179·75 Mc/s and 194·75 Mc/s). Each half of the aerial (4 tiers) was to be fed from a separate feeder (this arrangement is referred to as a split aerial) in order to provide continuity of service in the event of failure of part of the aerial or of other equipment.

Since the completion of the investigation the proposal to use a common aerial for two programmes has been abandoned. Moreover, it now appears that the gain of an 8-tier aerial would not be acceptable. Nevertheless, the work done is worthy of record, and the results will be of some value in the development of whatever aerial system is finally adopted. The remainder of this report, which was written before the change in requirements, is based entirely upon the original proposals.

The horizontal radiation pattern (h.r.p.) is required to be as uniform as possible, preferably with a maximum/minimum ratio not exceeding 3 dB. The specification of the impedance characteristic, which is discussed in Research Department Report No. E-046[1], is required to be met in each of the two channels. Since the second channel might not be allocated until after transmission on the first channel had begun it is desirable that after installation the aerial should be capable of adjustment to any two channels in Band III by means of convenient controls.

These requirements are similar to those specified for the Band III aerial for Sutton Coldfield, described in Research Department Report No. E-051[2]. The two aerials were therefore designed with as many features in common as possible. The principal difference lies in the size of the mast. At Sutton Coldfield the aerial will be mounted on an existing cylindrical mast which has too great a diameter to enable the h.r.p. requirement to be met, whereas the Crystal Palace mast was specifically designed for the Band III aerial and will be smaller. At the Crystal Palace the outside of the mast can be climbed, so that adjustment of the radiating elements can be undertaken more easily.

2. DESCRIPTION OF THE AERIAL.

The 40 ft (12 m) section of the tower designed to support the aerial will consist of four vertical rods, 7 in. (18 cm) in diameter and rigidly braced together, with their centres forming a square. It was originally intended that the side of the square should be 2 ft 6 in. (76 cm or 0·51λ) but this dimension was later increased to 4 ft 4 in. (1·32 m or 0·88λ) to allow more space inside the tower for the feeder system and climbing ladder etc. The interior of the mast will be screened by means of vertical strips 1 in. (2·5 cm) wide and spaced 6 in. (15 cm or 0·1λ) between centres. The strips will lie in the planes passing through the axes of the legs of the mast, and will be clamped to the inner surfaces of the bracing members, which will be outside these planes. In the model aerial the mast faces were simulated by the use of galvanised wire netting of 0·02λ mesh situated in the same planes as the screening strips.

Each of the 8 tiers of the aerial will consist of 4 tangential batwing elements oriented for vertical polarisation.

Fig. 1 shows the small-scale model of a single tier used in the experiments. The scale factor was 2·25. The batwing element, which is the basis of the American R.C.A. Superturnstile aerial, may be regarded as a skeletonised slot. Its use as a separate radiating element supported by a mast of large cross-section was first proposed for the Norwich Band I television aerial, which is described in Technical Memorandum No. E-1032[3]. In the present application it has two advantages. In the first place, its bandwidth, as determined by the impedance characteristic, is very good. Secondly, the radiation from each element corresponds to that originating from a pair of vertical dipoles spaced approximately one half-wavelength apart. It follows that, when mounted on a given mast, 4 tangential batwing elements can be arranged to give a more uniform horizontal radiation pattern than 4 vertical dipoles.

The model batwing element is shown in more detail in Figs. 2 and 3. Where dimensions are quoted in wavelengths, the wavelength should be taken to be 4·92 ft or 150 cm (corresponding to 200 Mc/s) at full scale and 2·19 ft or 67 cm (corresponding to 450 Mc/s) in the model. It will be seen that the element is supported by a pair of radial tubes, which also act as a balun. These tubes are each terminated in a rectangular box. A coaxial cable (Type PT1M) running inside one tube, has its outer conductor connected to the box, the inner being connected to the box terminating the

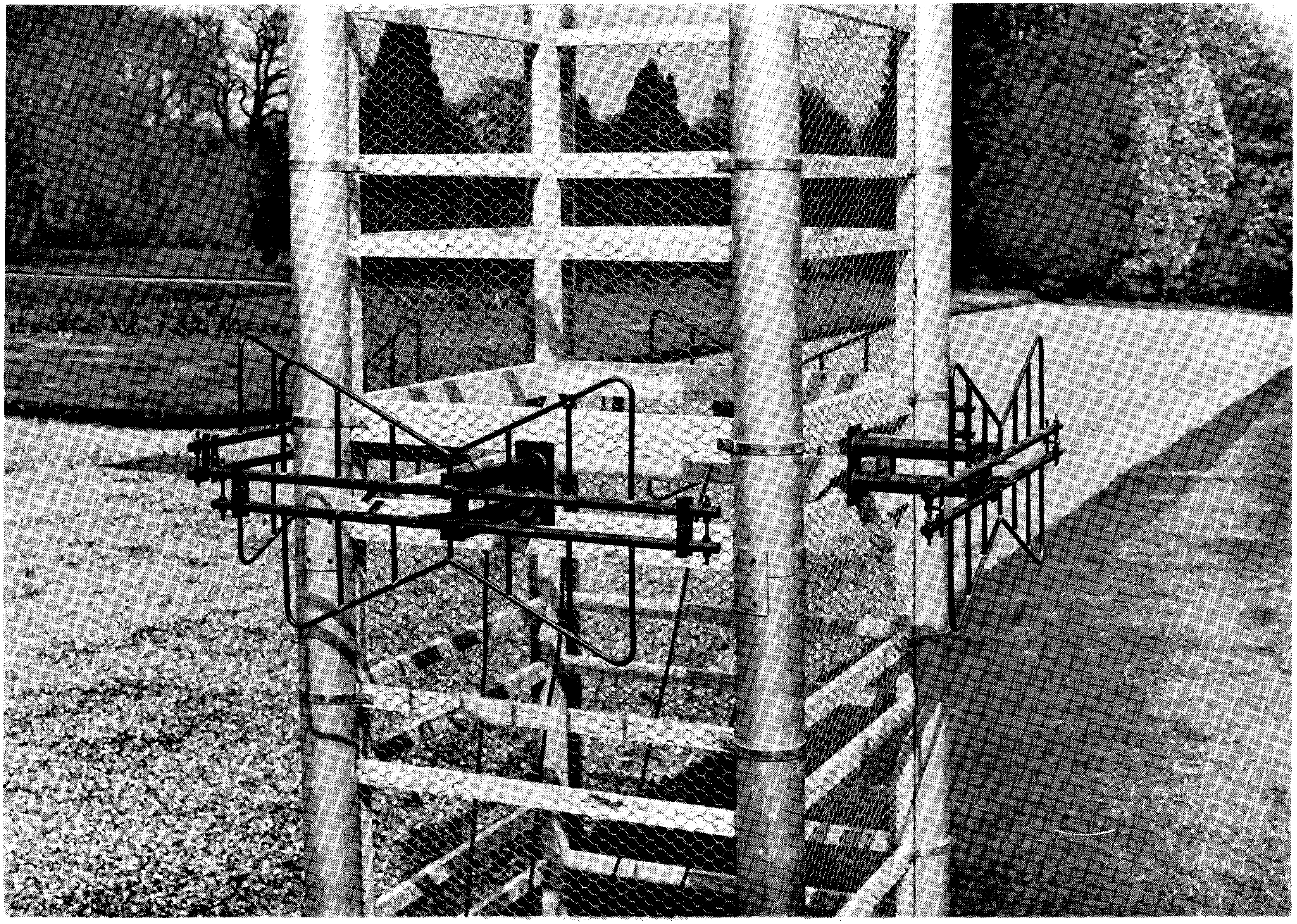


Fig. 1 - Model of one tier

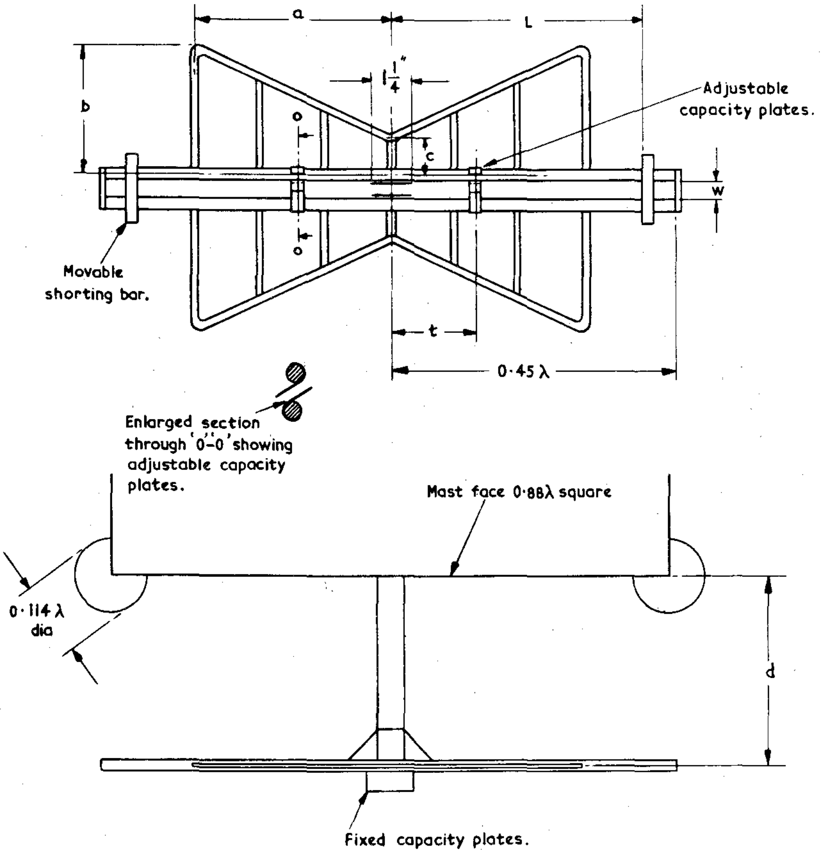


Fig. 2 - Model batwing element

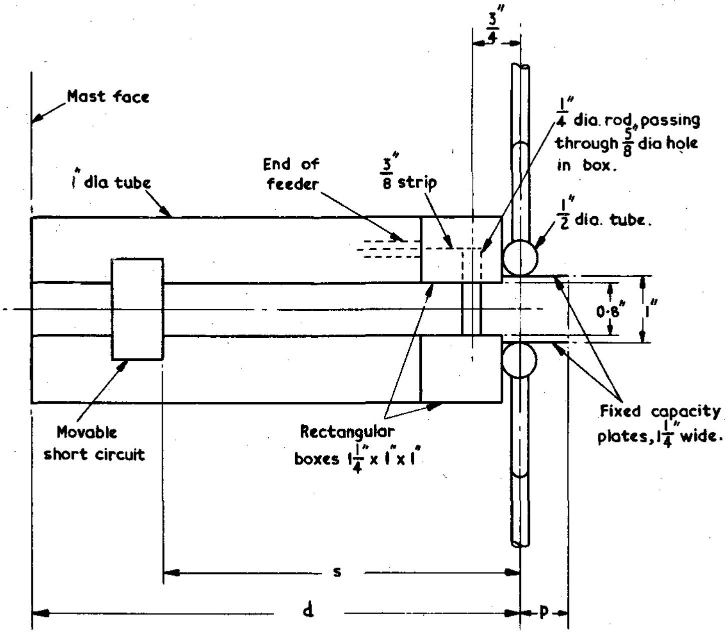
other tube by means of a vertical pillar. Adjustable capacity plates were located at points on either side of the centre of the element and movable shorting bars were provided to vary the lengths of the slot and the mounting stub. Fixed capacity plates were also provided at the centre of the element. The purpose of these controls will be discussed in Section 4.4 below.

3. RADIATION PATTERNS.

3.1. Horizontal Radiation Pattern.

Since a batwing element is almost equivalent to two parallel dipoles spaced approximately one half-wavelength apart it would be possible to arrange the 4 batwings of a tier so that the equivalent dipoles form a regular octagon. On a cylindrical mast this would produce a h.r.p. with eight-fold symmetry (i.e., the variation of field strength with azimuth has a period of 45°) and as a result the maximum/minimum ratio would be small over a wide frequency range. A square mast introduces a component of field strength varying with a period of 90°, but this can be compensated by changing the spacing of the batwings from the mast, so that the arrangement of the equivalent dipoles departs slightly from octagonal symmetry. The compensation holds only at one frequency, but by choosing this to be at the centre frequency of Band III a maximum/minimum ratio considerably less than 3 dB can be achieved over the whole of the band.

Eight-fold symmetry could be achieved at the centre frequency with a range of sizes of batwing element (different values of dimension "a", Fig. 2) provided that the spacing from the mast face is correctly chosen for each size. The choice of a combination of element size and spacing was influenced by the other considerations. Too great a spacing imposes an unnecessarily heavy wind loading. On the other hand, if the spacing is small the short mounting stub places a low inductance across the element, reducing its bandwidth and making control of impedance by variation of stub length impracticable.


3/4"
Mast face
1" dia tube
End of feeder
3/8" strip
1/4" dia. rod, passing through 5/8" dia hole in box.
1/2" dia. tube.
0·8"
1"
Fixed capacity plates, 1 1/4" wide.
Movable short circuit
Rectangular boxes 1 1/4" x 1" x 1"
s
d
p

Dimensions shown are of scale model.
Scale factor 1/2·25.

Fig. 3 - Mounting stubs for model batwing element

With the size of element finally chosen the spacing ("d", Figs. 2 and 3) was 0·285λ. This gave an eight-fold pattern with a maximum/minimum ratio of 1·6 dB at 450 Mc/s and maximum/minimum ratios of 2·2 dB and 1·5 dB at 400 and 500 Mc/s respectively. The size of element was then identical with that specified for the Band III aerial at Sutton Coldfield. The measured h.r.p. at 450 Mc/s is shown in Fig. 4.

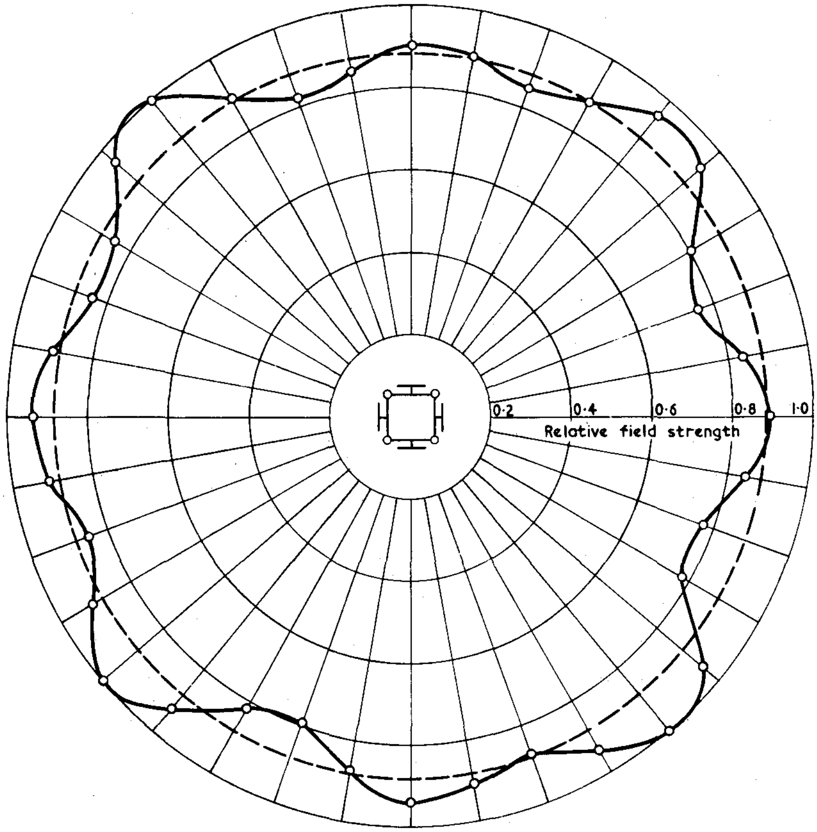
3.2. Vertical Radiation Pattern.

Vertical radiation patterns were measured in a plane perpendicular to a mast face and in a plane containing a mast diagonal, at 400, 450 and 500 Mc/s. In each case the patterns were similar in the two planes, differing only in magnitude. The average of the two measurements was therefore used for the calculation of the intrinsic gain (i.e. the gain ignoring all losses) of 8 tiers at the three frequencies. The results of the calculation are given in Table 1.

TABLE 1

Model frequency, Mc/s	400	450	500
Full-scale frequency, Mc/s	177·5	200	222·5
Inter-tier spacing, wavelengths	0·90	1·02	1·13
Calculated intrinsic gain, dB	9·4	9·7	9·5

The effective gain, taking account of gapfilling (see Section 5) and losses, will be discussed in Section 6.



o Measured points.

— — — R.M.S. field strength.

Fig. 4 - Measured h.r.p. at 450 Mc/s

4. ADMITTANCE.

4.1. Requirements.

The admittance presented to the main feeder by the aerial system must satisfy the specification laid down in Research Department Report No. E-046 in each of two Band III channels, but it is not proposed to attempt to match each batwing element to this degree of accuracy. Instead, it is intended to match the elements as well as possible over the whole of Band III (176 Mc/s to 216 Mc/s). Then, by means of two suitably spaced controls inserted in the feeders, the main feeder will be matched exactly (within the limits of experimental error) at the two vision carrier frequencies. Each of these controls will introduce a reflection coefficient of variable magnitude and phase; a possible design could consist of a short length of line of high characteristic impedance with two adjustable shunt capacitors spaced one eighth of a wavelength apart. One of the controls should be placed as close to the elements as possible, i.e., at the top of the main feeder supplying one half of the aerial. The other control should be placed lower in the main feeder, at a distance depending on the frequency separation between the two channels. For a separation of 15 Mc/s the distance between the controls should be about 16 ft or 5 m (one quarter-wavelength at 15 Mc/s).

This method of matching has the advantage that the final adjustment can be carried out inside the mast. Furthermore no adjustment to the elements would be necessary in the event of a change of channel allocation.

It would be possible to match the aerial at the vision carrier frequencies by means of the two controls whatever the impedance of the elements, but the resulting reflection coefficient at the vision sideband frequencies might then be outside the limits specified in E.046. It was found by calculation, assuming typical aerial admittance characteristics, a feeder loss of 1.3 dB, and a channel separation not exceeding 20 Mc/s, that the specification can be met without difficulty provided the standing-wave ratio (s.w.r.) of the elements exceeds 0.8 over the band. Thus the object of the admittance measurements on the model was to match the elements to a standing-wave ratio greater than 0.8 over the frequency range 400–500 Mc/s. Each of the two admittance controls provided in the feeder system should be capable of introducing a reflection coefficient of any phase and any magnitude up to 0.1.

4.2. Method of Measurement.

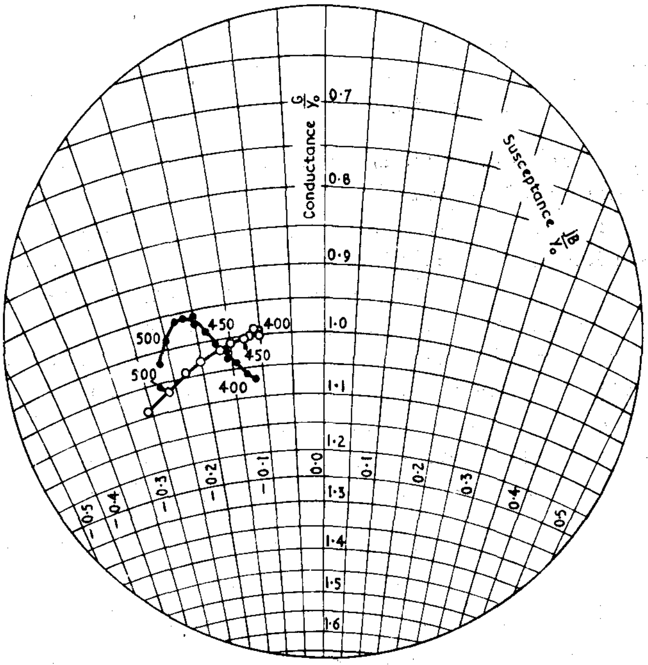
Preliminary measurements of the admittance were performed on a single batwing element, the admittance of which had been found to differ only slightly from that of a tier of 4 elements. The element was connected through a 10 ft (3 m) length of PT1M cable to a General Radio Admittance Meter, modified for operation with 70-ohm cable. The final measurements were performed on 4 elements, a double quarter-wave transformer being inserted between the cables and the admittance meter. The measuring system was calibrated by connecting four long terminated cables to the transformer and noting the admittance presented to the meter when they were well-matched. The cables were then cut to the required length and their electrical length and loss determined in a separate experiment. All the admittance measurements are normalised to the characteristic admittance of PT1M cable (13.8 ± 0.3 mmho).

4.3 Mutual Admittance.

A reasonable admittance characteristic having been obtained with one element, the 4 elements were arranged as two half-tiers, i.e., two of the elements were mounted on adjacent faces and the other two elements were mounted vertically above them. The admittance of this arrangement is very nearly equal to that of two tiers since the mutual admittance between elements mounted on different faces of the mast is known to be small.

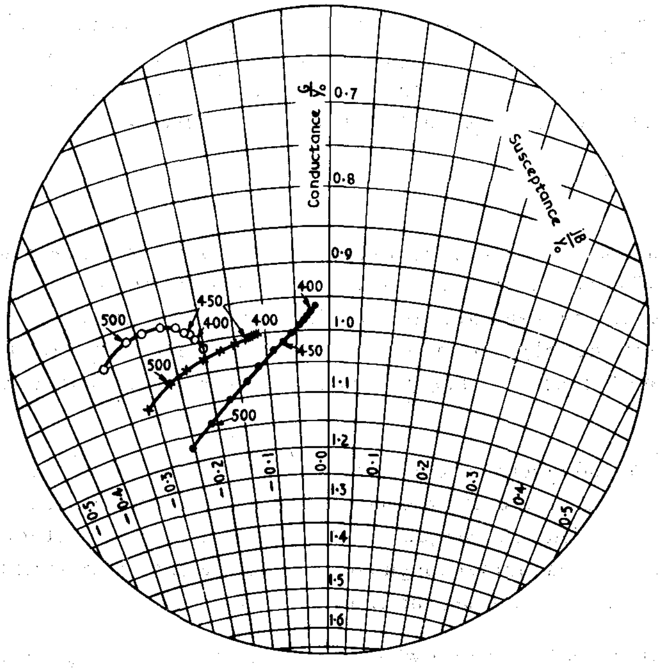
The mutual admittance between adjacent tiers was determined as one-half of the change in admittance when the phase of one tier was reversed. The admittance of an 8-tier aerial was then estimated by adding three-quarters of the mutual admittance to the value measured with the two half-tiers driven in phase. (The mutual admittance between tiers which are not adjacent is small and may be neglected).

Changes were made to the elements of the two half-tiers until the optimum 8-tier admittance was obtained with the adjusting controls in their central positions. The final result for two half-tiers is shown in Fig. 5 together with the estimated 8-tier admittance. By adding capacity across the end of the feeder, so as to move the 8-tier admittance to the centre of the admittance diagram, the s.w.r. could be made greater than 0.9 over the range 400–500 Mc/s; as stated in Section 4.1 the minimum permissible s.w.r. is 0.8.



—○—○— Measured admittance of two half-tiers
—●—●— Estimated admittance of eight tiers
Numbers denote model frequencies in Mc/s
(=2·25 x full scale frequency).

Fig. 5 - Measured admittance of aerial



—×—×— Measured admittance with dimensions given in table 2
—○—○— Slot lengthened by 2·3 %.
—●—●— Slot shortened by 2·3 %.
Numbers denote model frequency in Mc/s.

Fig. 6 - Admittance of two half-tiers showing effect of change of slot length

4.4. Method of Adjusting Elements.

Three controls are provided for adjusting the shape and position of the admittance characteristic. They are:

i. Variation of slot length ("L", Fig. 2).

ii. Variation of length of mounting stub ("s", Fig. 3).

iii. Variation of capacitance across the slot at points approximately one eighth-wavelength from the centre of the element.

The effect of changing the slot length is shown in Fig. 6, where it will be seen that this control rotates and changes the shape of the admittance curve. It should therefore be adjusted until the estimated admittance curve for 8 tiers covers the smallest possible area on the admittance diagram.

The effects of the other two controls are shown in Fig. 7; they move the admittance curve in orthogonal directions without greatly affecting its shape. But since the admittance curve cannot be moved to the centre of the diagram with these controls alone, it is recommended that the curve should be centred as well as possible by introducing fixed capacitance at the end of the coaxial feeder. Controls (ii) and (iii) may then be used for fine adjustments.

The final dimensions of the elements in wavelengths are summarised in Table 2 together with the dimensions at full scale.

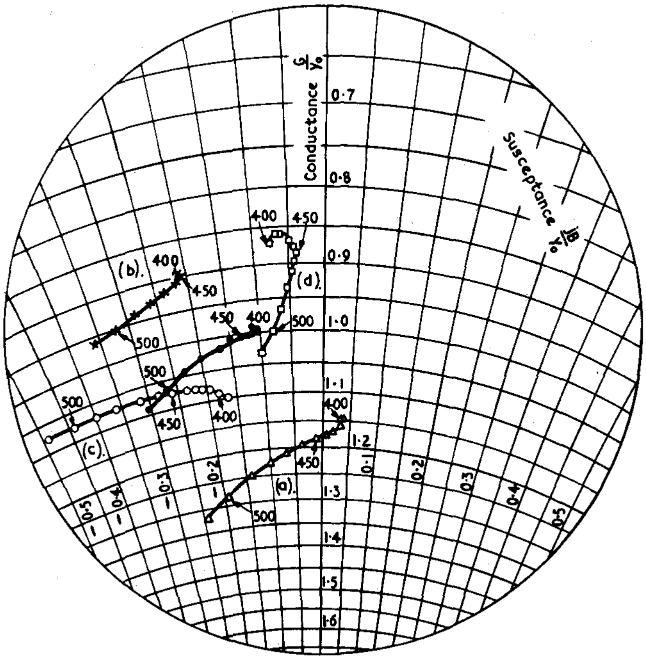
TABLE 2

Distance of batwing centres from axis of tower	0·73λ	(3 ft 7 in.	= 109 cm)
Distance of batwing centres from face of tower	d = 0·29λ	(1 ft 5 in.	= 43 cm)
Dimensions of batwing element	a = 0·33λ	(1 ft $7\frac{1}{2}$ in.	= 49·5 cm)
	b = 0·22λ	(1 ft 1 in.	= 33 cm)
	c = 0·062λ	($3\frac{5}{8}$ in.	= 9·2 cm)
Diameter of tubes forming slot	0·019λ	($1\frac{1}{8}$ in.	= 2·9 cm)
Distance between centres of tubes forming slot	0·057λ	($3\frac{3}{8}$ in.	= 8·6 cm)
Slot half-length for admittance shown in Fig. 5	L = 0·41λ	(2 ft $0\frac{1}{4}$ in.	= 61 cm)
Maximum possible slot length	0·45λ	(2 ft $2\frac{1}{2}$ in.	= 67 cm)
Slot width	w = 0·038λ	($2\frac{1}{4}$ in.	= 5·7 cm)
Diameter of tubes forming mounting stub	0·038λ	($2\frac{1}{4}$ in.	= 5·7 cm)
Distance between centres of tubes forming mounting stub	0·068λ	(4 in.	= 10 cm)
Length of mounting stub for admittance shown in Fig. 5	s = 0·21λ	(1 ft $0\frac{1}{2}$ in.	= 32 cm)
Width of fixed capacity plates at centre of element	0·05λ	(3 in.	= 7·6 cm)
Extension of fixed capacity plates at centre of element	p = 0·03λ	($1\frac{3}{4}$ in.	= 4·5 cm)
Distance of adjustable capacity plates from centre of element	t = 0·15λ	(9 in.	= 23 cm)
Value of each of the adjustable capacitances for the admittance shown in Fig. 5	0·2 pf (model) 0·45 pf (full scale)		

5. RECEPTION NEAR TO THE AERIAL.

Unlike most transmitting stations having high-gain aerial systems, the Crystal Palace station is sited in a built-up area. For this reason it is essential to ensure reasonable signals in the immediate vicinity.

If all 8 tiers were energised equally and in phase, the vertical radiation pattern (v.r.p.) would exhibit minor lobes separated from each other and from the main lobe by deep minima, which would result in circular zones of comparatively low field strength. This effect is illustrated by the broken curve in Fig. 8 which represents the theoretical field strength at ground level as a function of distance. This curve neglects reflection at the ground, which would require to be taken into account when computing the strength of a received signal, but this will not greatly affect the positions of the minima. Variations in ground level are also neglected.



Central curve: measured admittance with dimensions given in table 2
(a). Mounting stub lengthened by 36 %.
(b). Mounting stub shortened by 18 %.
(c). Adjustable capacitors removed.
(d). Adjustable capacitors doubled in value.
Numbers denote model frequency in Mc/s.

Fig. 7 - Effect of adjustments provided on the admittance of two half-tiers

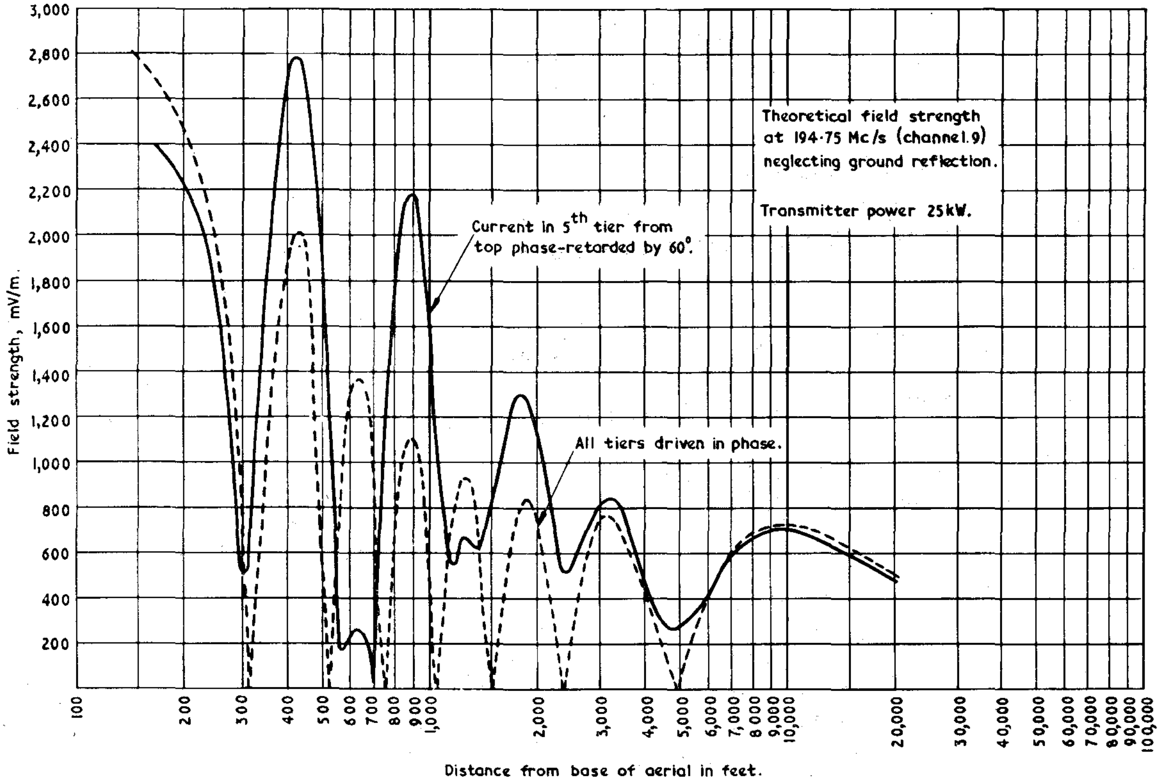


Fig. 8 - Field strength near to the transmitter

In practice, it is unlikely that the field strength would fall to zero in the minima, as shown in Fig. 8, or even to a value comparable with the noise level. In practice the minima would be filled in to some extent as a result of small discrepancies between the amplitudes and phases of the currents in the elements of the aerial, ground reflection near to the receiving point, and scattering from buildings. Nevertheless, the signals received in the zones of minimum field strength would be unsatisfactory. Multipath propagation would be much more probable than elsewhere, and large differences could exist between the field strengths of the two transmissions. Moreover, in alternate minima the field strength would be extremely sensitive to changes in the relative amplitudes and phases of the feeds to the two halves of the aerial, so that small variations could give rise to a fading effect. The remedy is to modify the v.r.p. of the aerial in order to fill in the minima directly, so that the viewer is not obliged to depend on fortuitous and distorted signals. This process may be termed "gapfilling".

In order to fill in the minima shown in the broken line curve of Fig. 8 it is necessary to introduce a component of field strength in phase quadrature with that on either side of the minimum. One method would be to install an additional tier of elements at the centre of the aerial, and to feed it in phase quadrature with the other 8 tiers, but in practice it would be highly inconvenient to add additional elements to a split aerial system. Instead, it is intended to adopt a simpler method, which is considered to offer a reasonable compromise between simplicity and performance. No additional elements will be added, but the phase of the 5th tier from the top, i.e., the upper tier of the lower half of the aerial, will be retarded by 60°. The effect, which is illustrated by the full line curve in Fig. 8, is to fill partially the four outer minima. The 5th minimum (at 750 ft or 230 m) is merely shifted slightly inwards. It is considered that satisfactory reception will be ensured at distances greater than 800 ft (245 m). There are a few houses, less than twanty, within this range, but only a proportion of these would receive poor signals. Moreover, at such short range poor signals could probably be improved by moving or tilting the receiving aerial.

Calculations have been made to determine the extent to which the field strength in the neighbourhood of the minima would fluctuate as a result of variations in the relative phases and amplitudes of the feeds to the two halves of the aerial. This effect is found to be most marked in the case of the furthest minimum at 5000 ft (1500 m), (ranges less than 800 ft or 245 m are not considered), but it is reduced to acceptable proportions by the proposed method of gapfilling. For example, a reduction of 2 dB in the power radiated from the upper half of the aerial would reduce the field strength in the furthest minimum by 7 dB. A phase difference of 40° between the feeds to the halves of the aerial would reduce the field in the furthest minimum by 6 dB. Such a large phase difference would not be tolerated in any case, since it would result in a loss of 0.5 dB in field at the fringe of the service area.

In the emergency condition when only one half of the aerial will be used, alternate minima, including the outermost minimum, will disappear. The remaining minima will not be satisfactorily filled in whichever half of the aerial is in use.

The loss of gain, i.e., the reduction in field strength at distances exceeding a few miles, resulting from the proposed method of gapfilling, is estimated to be 0.5 dB.

One method of achieving the required phase retardation of 60° is to lengthen the feeder supplying the 5th tier from the top by about 10 in. (25 cm). Since this may prove mechanically inconvenient, it may be preferable to maintain the physical length of the feeder unchanged, but to increase its electrical length by modifying the inner conductor. This can be done by reducing the diameter and fitting capacitative sleeves.

6. EFFECTIVE GAIN.

The effective gain of the aerial system is calculated in Table 3, for a frequency of 200 Mc/s.

7. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK.

The development has been taken to a point at which a fully-engineered design for the aerial and feeder system can be prepared. Although the elements will be similar to those developed for Sutton Coldfield[2], there will be a number of differ-

TABLE 3

Intrinsic gain, ignoring gapfilling	9.7 dB
Deduct loss of gain in gapfilling	0.5 dB
Leaving	9.2 dB
Deduct loss in distribution feeders	0.1 dB
Loss due to accidental misphasing etc.	0.2 dB
Leaving aerial net gain	8.9 dB
Deduct loss in 700 ft (215 m) of 5 in. feeder (12.7 cm)	1.1 dB
Loss in filters and miscellaneous losses	0.2 dB
Leaving effective gain	7.6 dB
i.e. power ratio	5.75

ences, arising from the differing dimensions of the supporting masts. When the design has been completed, it is recommended that admittance measurements should be made on 4 elements arranged in two half-tiers. It is essential that these elements should include the termination of the coaxial feeder at the mid-point, with any supporting insulator, since this is the feature that is likely to depart most widely from the model. After any necessary modifications have been made, it is recommended that further measurements should be made on 8 elements assembled in two complete tiers.

The object should be to obtain an admittance characteristic which gives the best match over the whole of Band III after allowance has been made for mutual admittance. The optimum shape of the admittance characteristic should be obtained by adjusting the length of the slot. It should then be possible, by variation of the adjustable capacitors and the length of the mounting stub, to obtain a range of adjustment approximately corresponding to that shown in Fig. 7. It is hoped that the settings arrived at on the prototype elements will not require alteration after installation of the complete aerial at Crystal Palace, although this would be less difficult to perform than at Sutton Coldfield.

8. REFERENCES.

1. "Specification of the Impedance Characteristics of Television Transmitting Aerial Systems", Research Department Report No. E-046, Serial No. 1953/18, July, 1953.

2. "Vertically-Polarised Band III Aerial for Sutton Coldfield", Research Department Report No. E-051, Serial No. 1955/29

3. "Horizontally-Polarised Directional Band I Aerial for the Norwich Medium-Power Television Station", Research Department Technical Memorandum No. E-1032.